ESC201AT : Introduction to Electronics

Lecture-3 : Tools For Circuit Analysis-1

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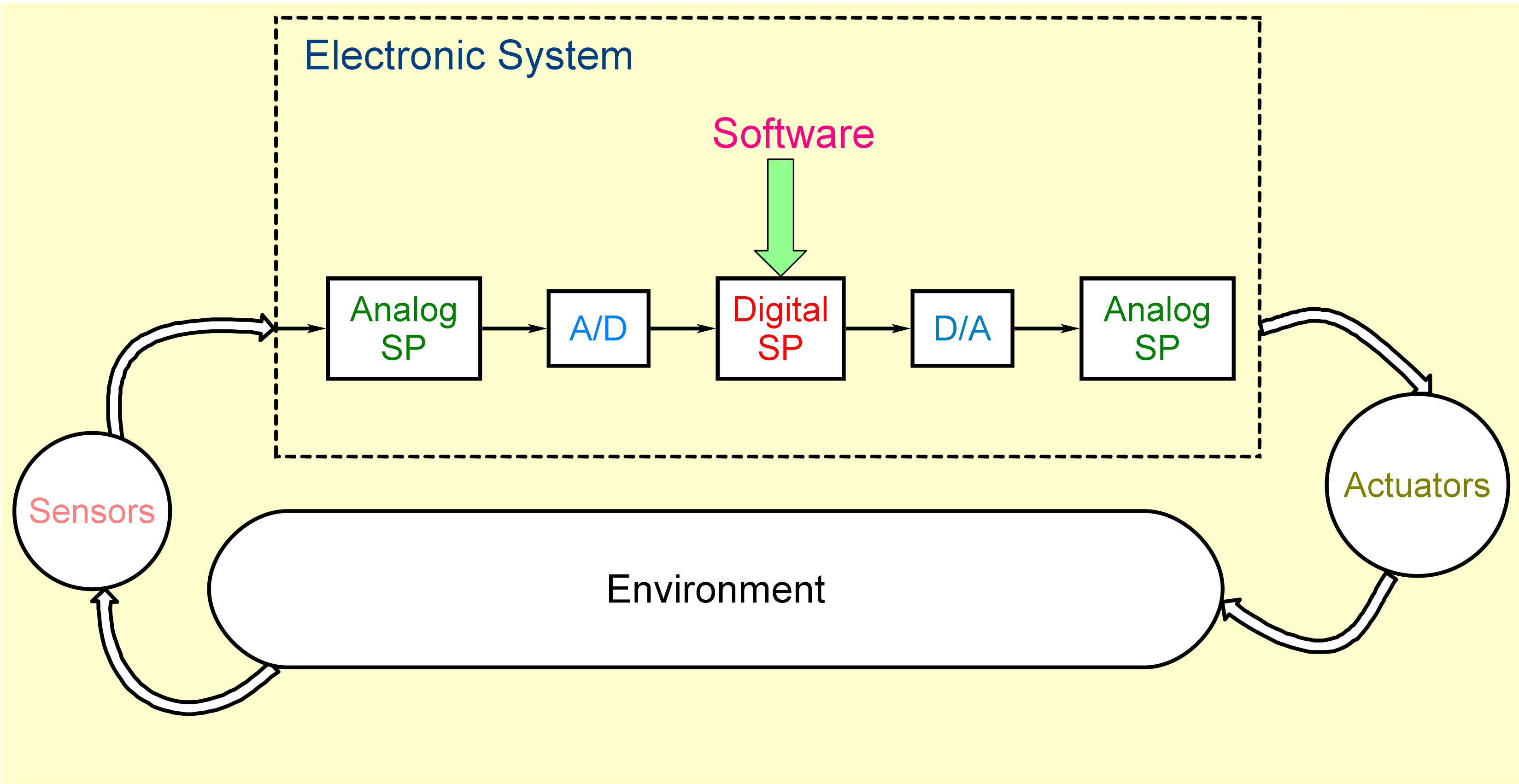
Problem Solving Using Electronics



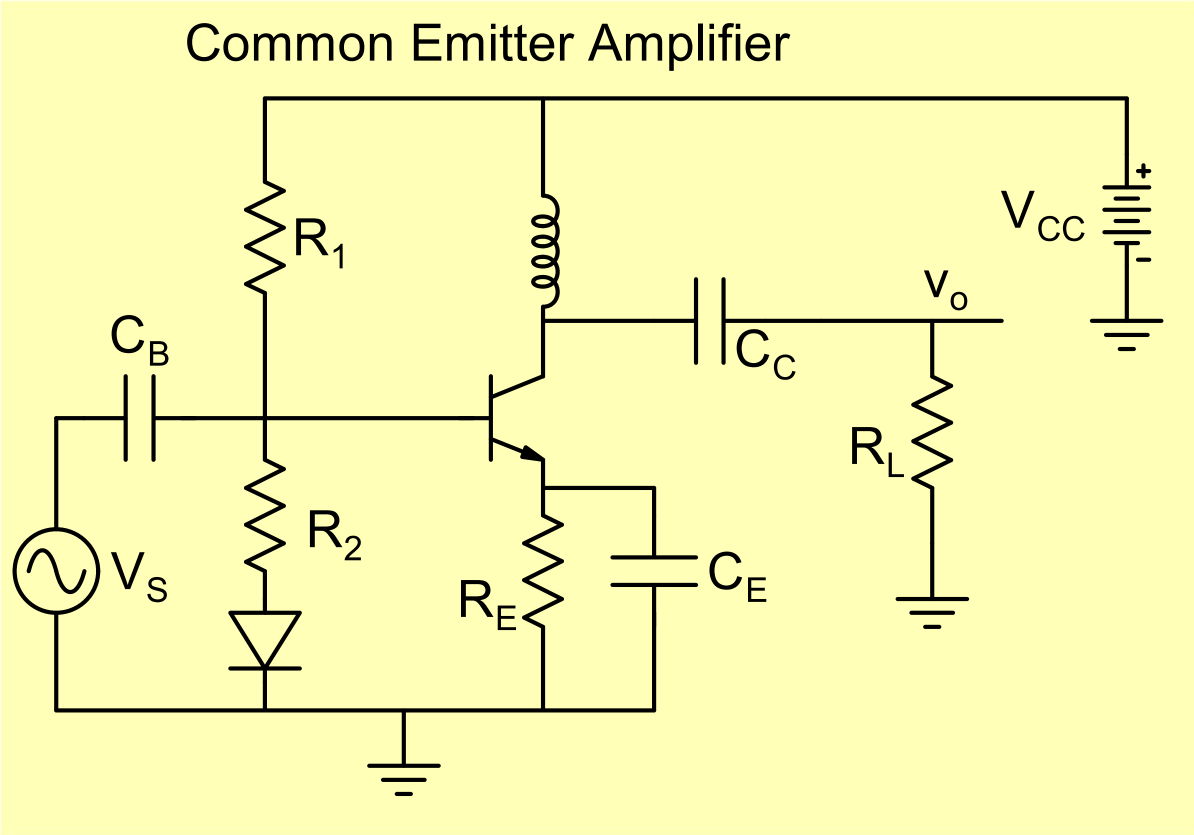
In ESC201A we learn by analyzing and designing analog and digital circuits

Toolbox

We need to equip ourselves with tools for circuit analysis

Electrical Circuit

Connection of several circuit elements in closed paths by conductors

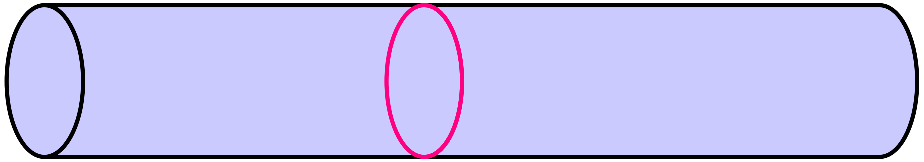


Before we learn how to analyze and design circuits, we must become familiar with some basic circuit elements.

Electrical Current

The time rate of flow of electrical charge

– The units are amperes (A), which are equivalent to coulombs per second (*C/s)*

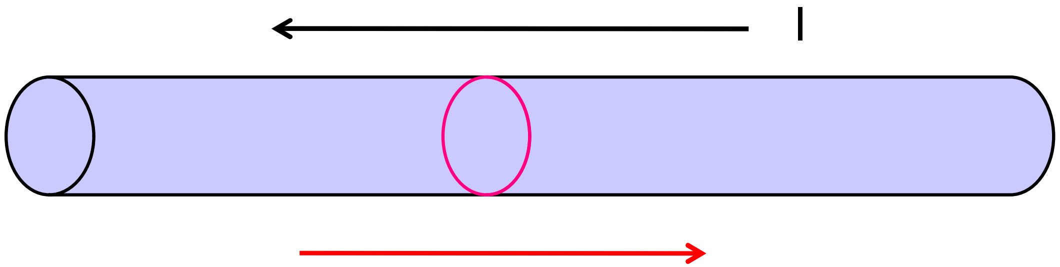


$$i(t) = \frac{dq(t)}{dt}$$

Flow of electrons through a wire or other electrical conductor gives rise to current

• Electrons are negatively charged particles

The charge per electron is **-1.602×10^{-19} *C***



10^{16} electrons flow per second

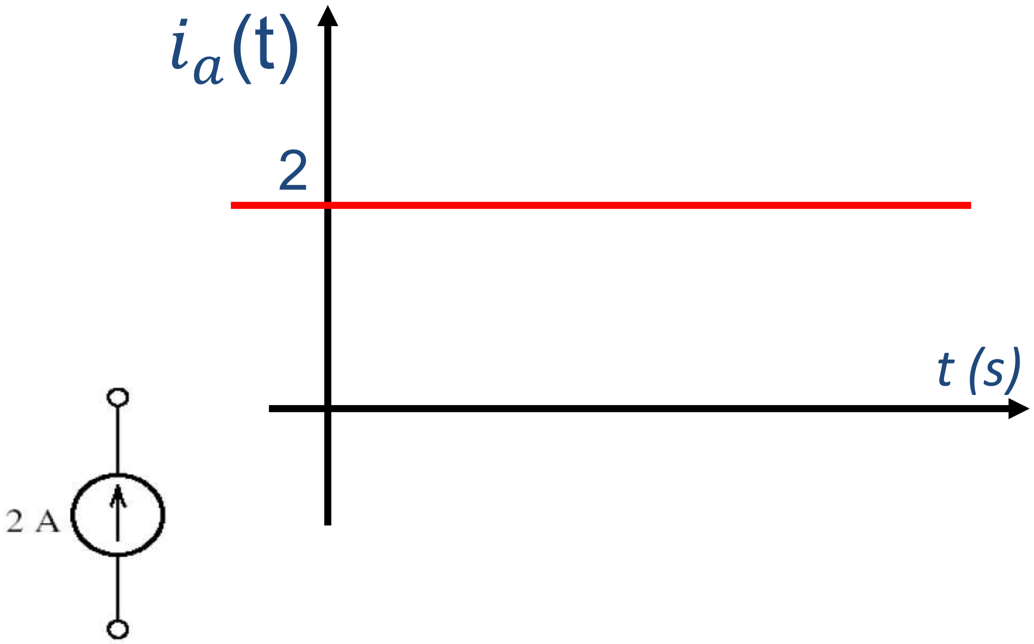
Large number of electrons have to flow for appreciable current

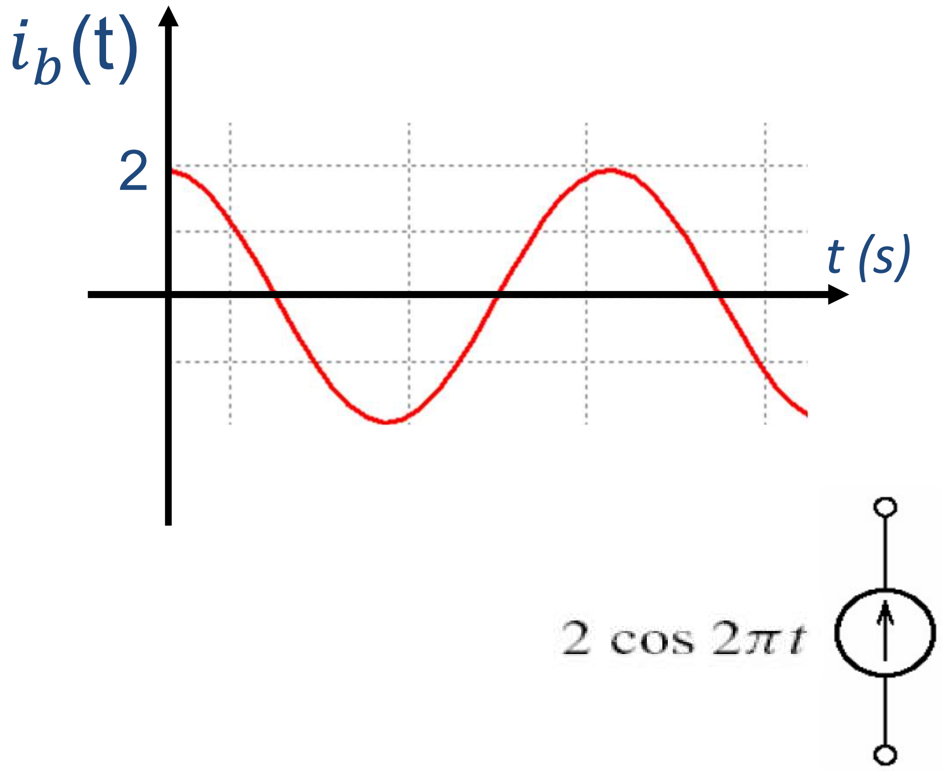
How much current flows? $$i(t) = \frac{dq(t)}{dt}$$

$$I = \frac{Q}{t} = \frac{-1.6\times10^{-19}\times10^{16}}{1} = -1.6\times10^{-3}\,A$$

Direct Current (DC) & Alternating Current (AC)

When current is constant with time, we say that we have direct current, abbreviated as DC.



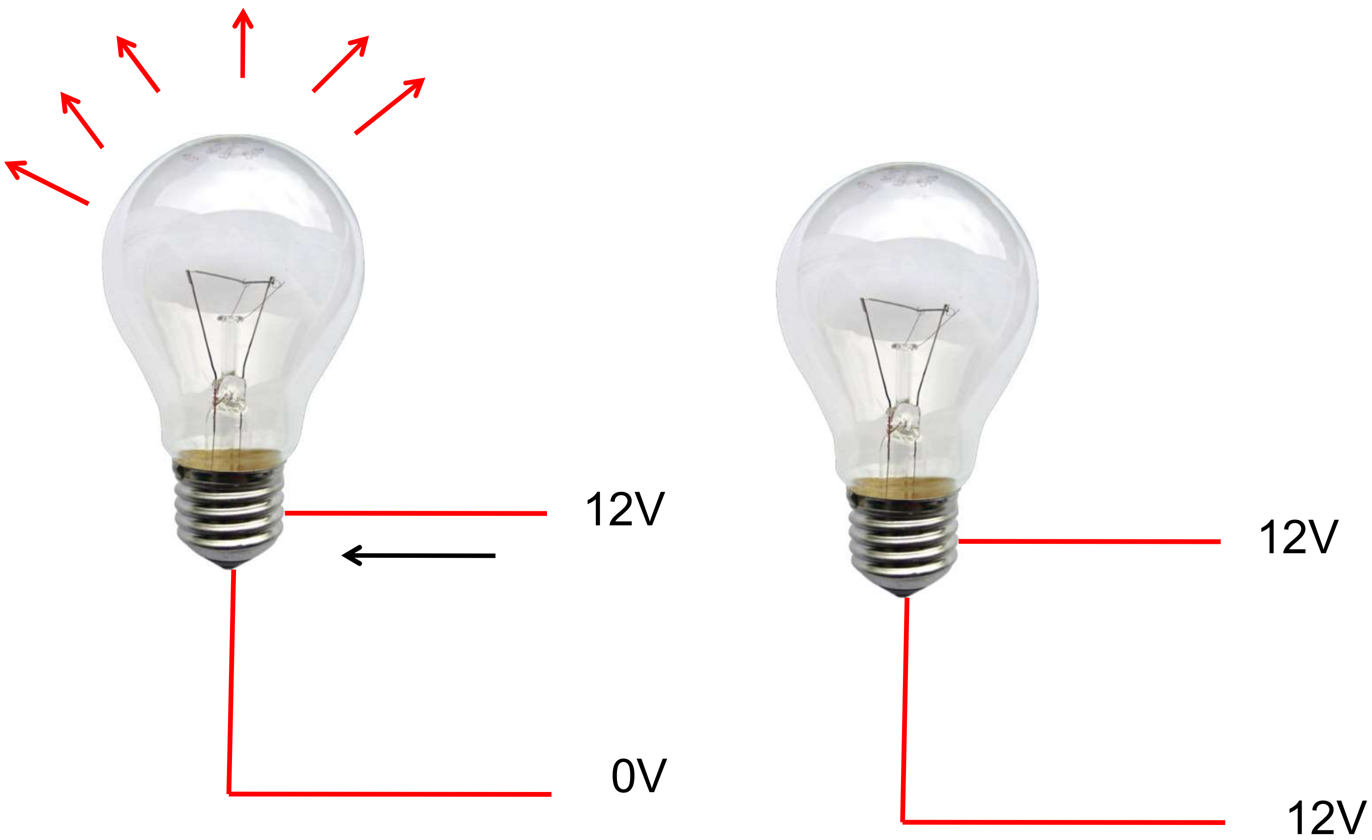


On the other hand, a current that varies with time, reversing direction periodically, is called alternating current, abbreviated as **AC**

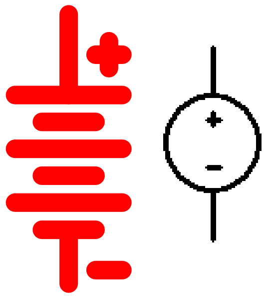
Voltage

Voltage difference is a Source of current flow

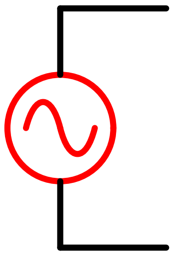
Units of Voltage: Volts (V)

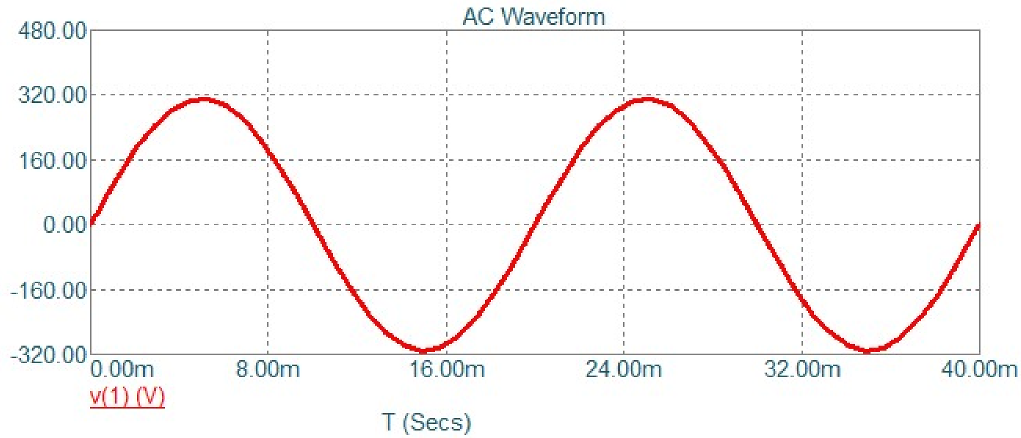


DC and AC voltages

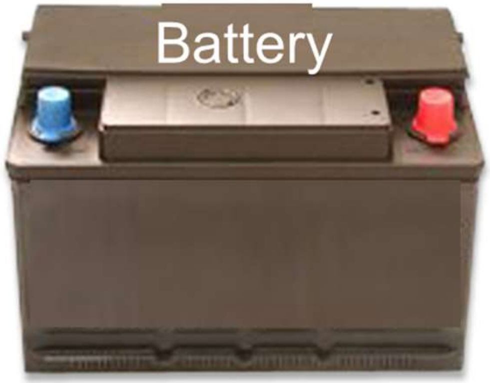


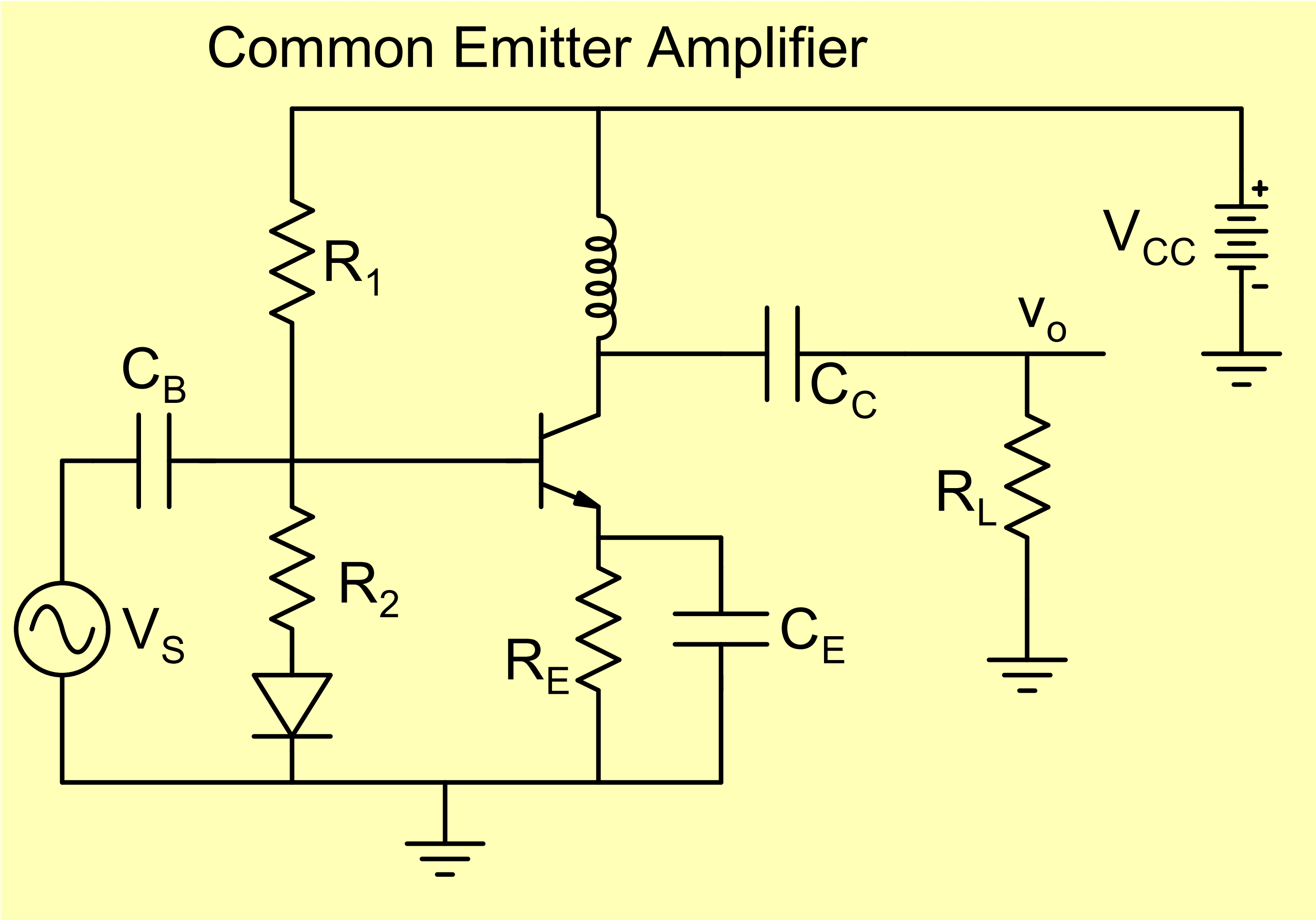
$$V_+ - V_- = 12V$$



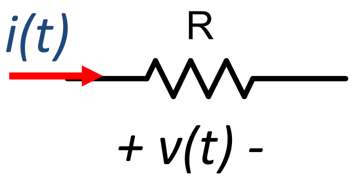


Voltage Sources




Common Emitter Amplifier
R1
R2
CB
VS
RE
CE
CC
vo
RL
VCC
+
-

Resistance



$$v(t) = R \times i(t)$$

Ohm's law

The constant, *R, is called the resistance and is* measured in units of Ohm (Ω)

Standard Multiples of Ohm

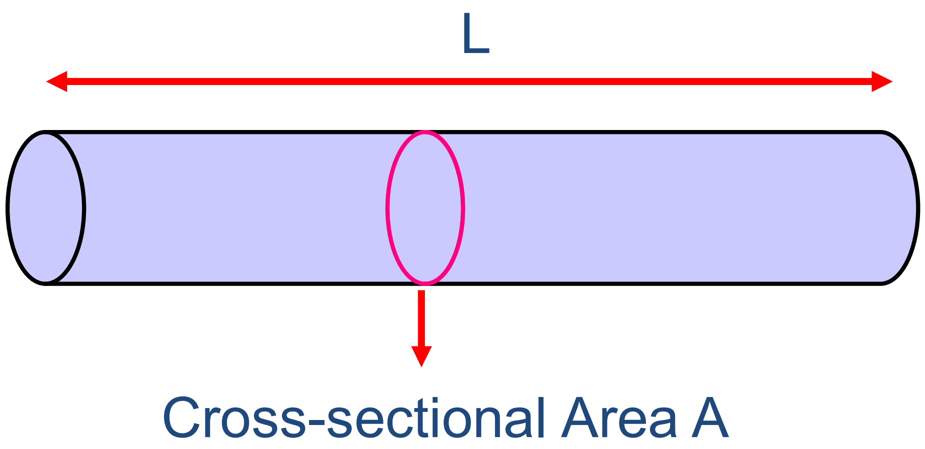
$M\Omega$ Mega Ohm ($10^6\,\Omega$)

$k\Omega$ Kilo Ohm ($10^3\,\Omega$)

$$i(t) = \frac{v(t)}{R} = G \times v(t)$$

G = 1/R is called conductance and its unit is Siemens (S)

Resistance Related to Physical Parameters

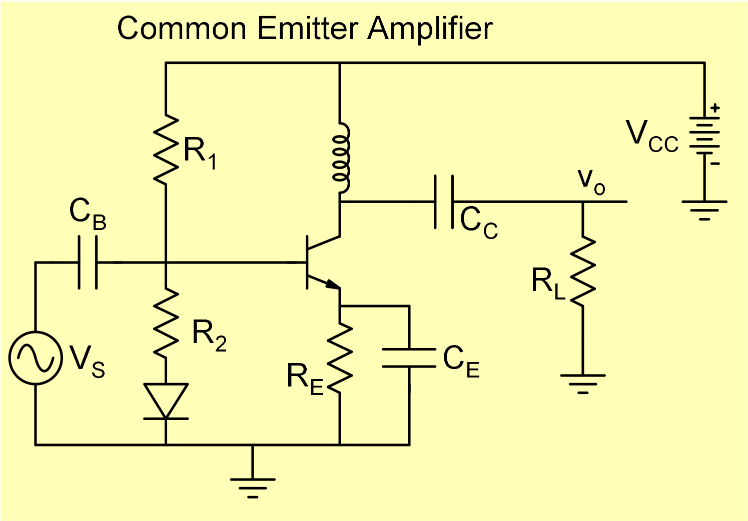


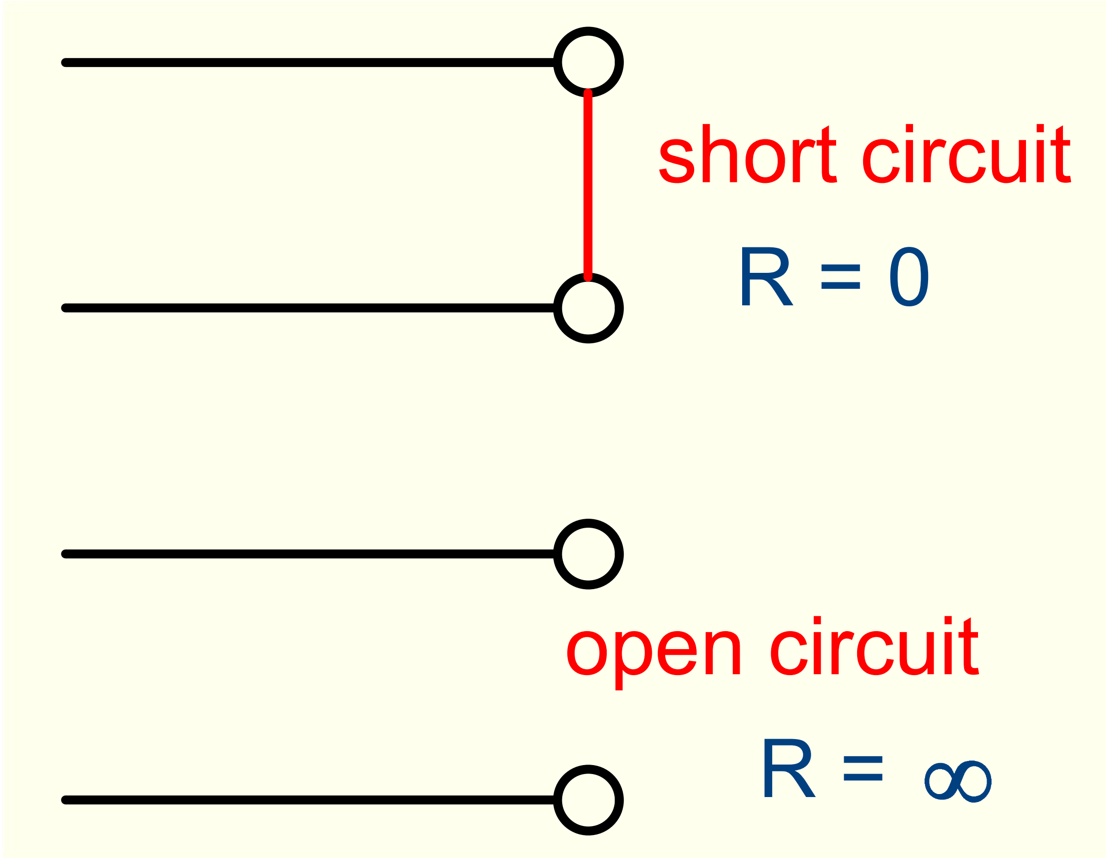
$$R = \rho \times \frac{L}{A}$$

Resistance is affected by the dimensions and geometry of the resistor as well as the particular material used

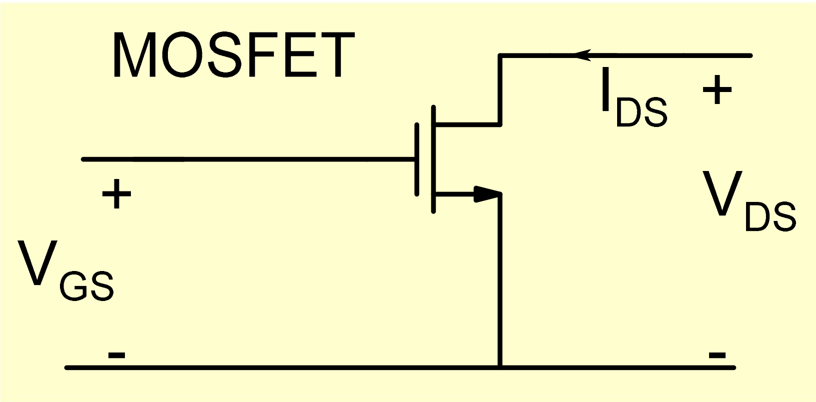
ρ is the resistivity of the material in ohm meters [Ω-m]
– Conductors (Aluminum, Carbon, Copper, Gold)
– Insulators (Glass, Teflon)
– Semiconductors (Silicon)

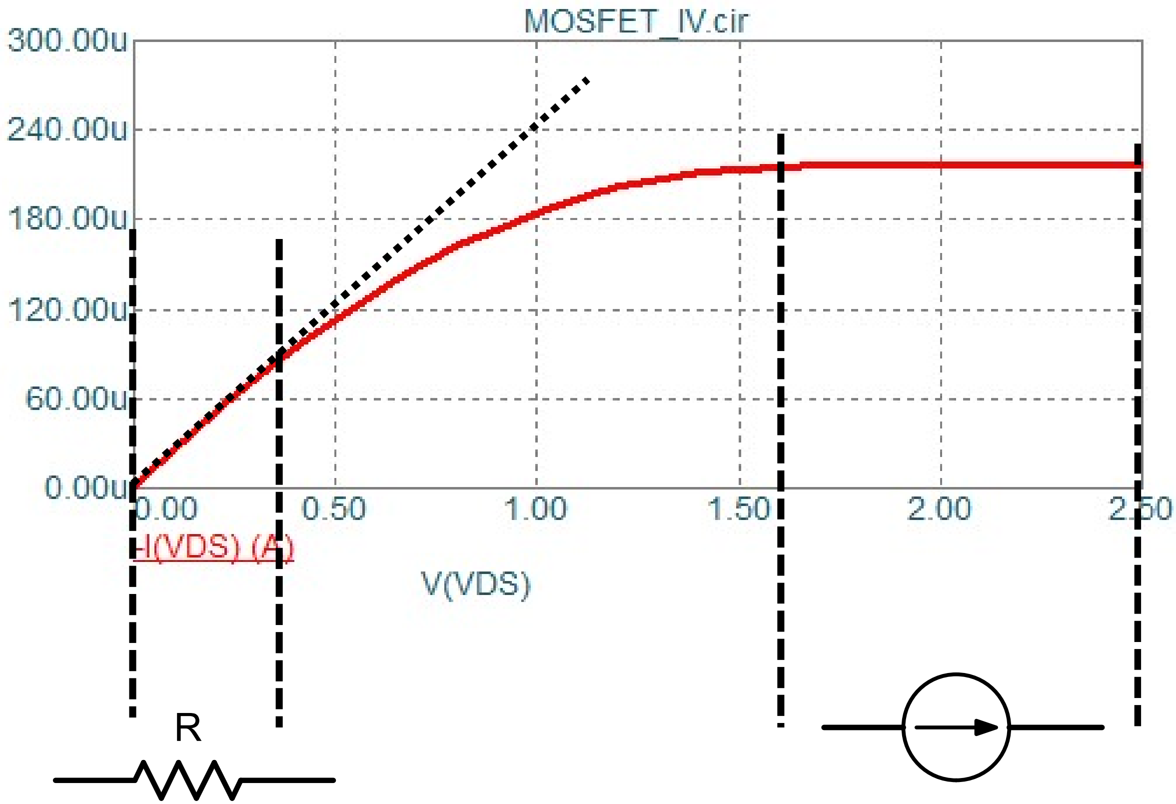
Two special resistors



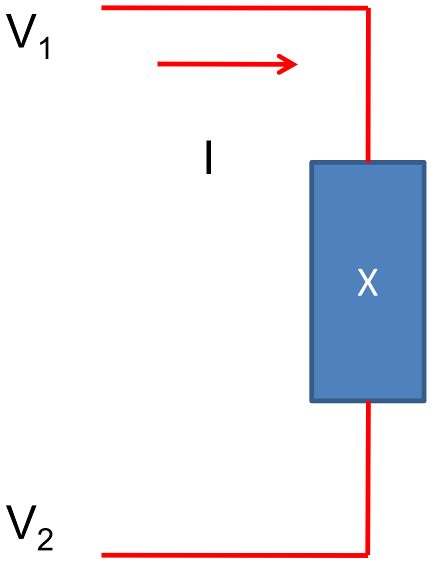


Any electrical element which has linear current voltage characteristics over a certain voltage range can be **modeled** as a resistor in that range





Power

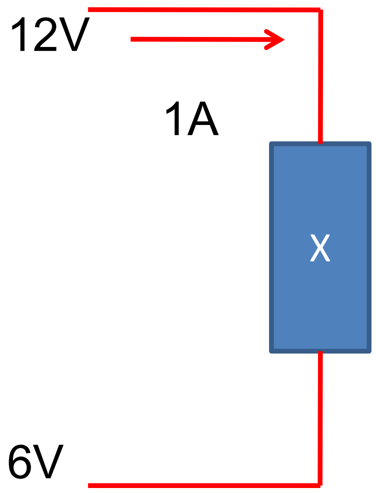


$$P = (V_1 - V_2) \times I$$

If $V_1 > V_2$ then P is positive and it means that power is being delivered to the electrical element X

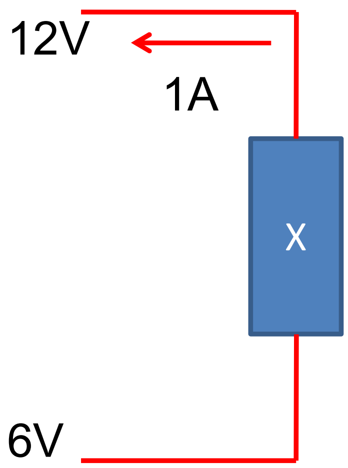
If $V_1 < V_2$ then P is negative and it means that power is being extracted from the electrical element X. X is a source of power !

Examples



P = ?

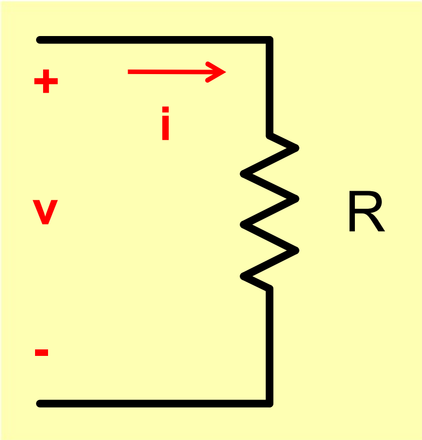
$$P = (V_1 - V_2) \times I$$
$$= (12 - 6) \times 1 = 6W$$



P = ?

$$P = (V_1 - V_2) \times I$$
$$= (12 - 6) \times -1 = -6W$$

Power dissipated in a Resistor



$$v = i \times R$$

$$i = \frac{v}{R}$$

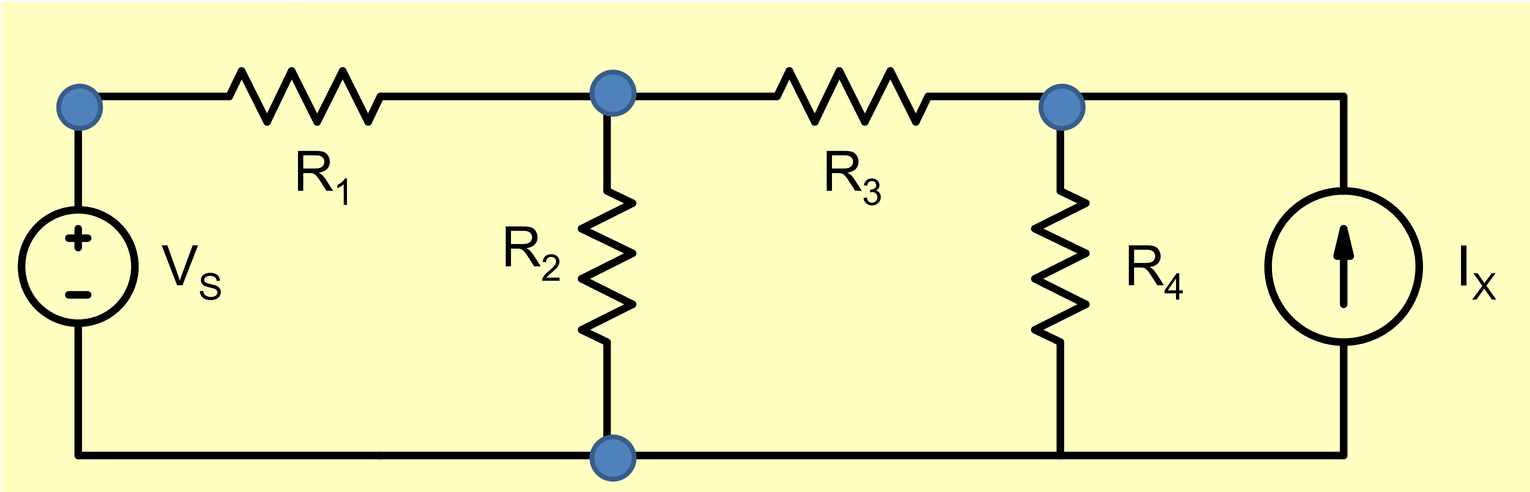
$$P = v \times i$$

$$P = i^2 \times R$$

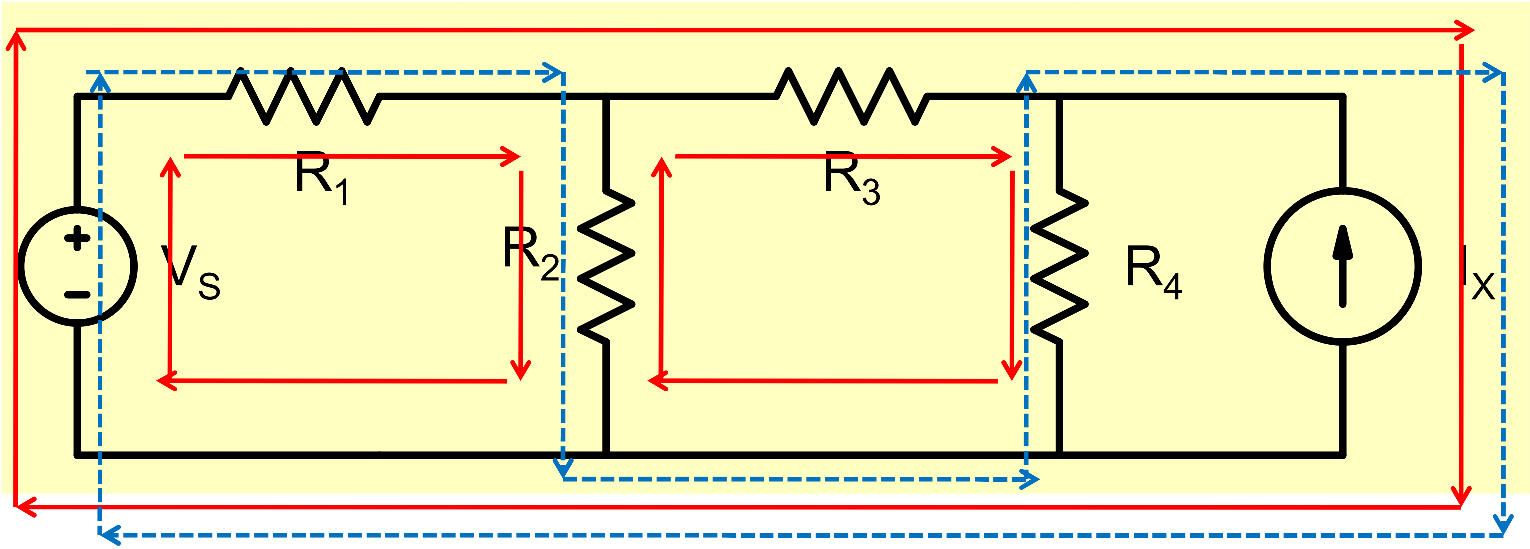
$$P = \frac{v^2}{R}$$

Nodes and loops

Node: A point where 2 or more circuit elements are connected.

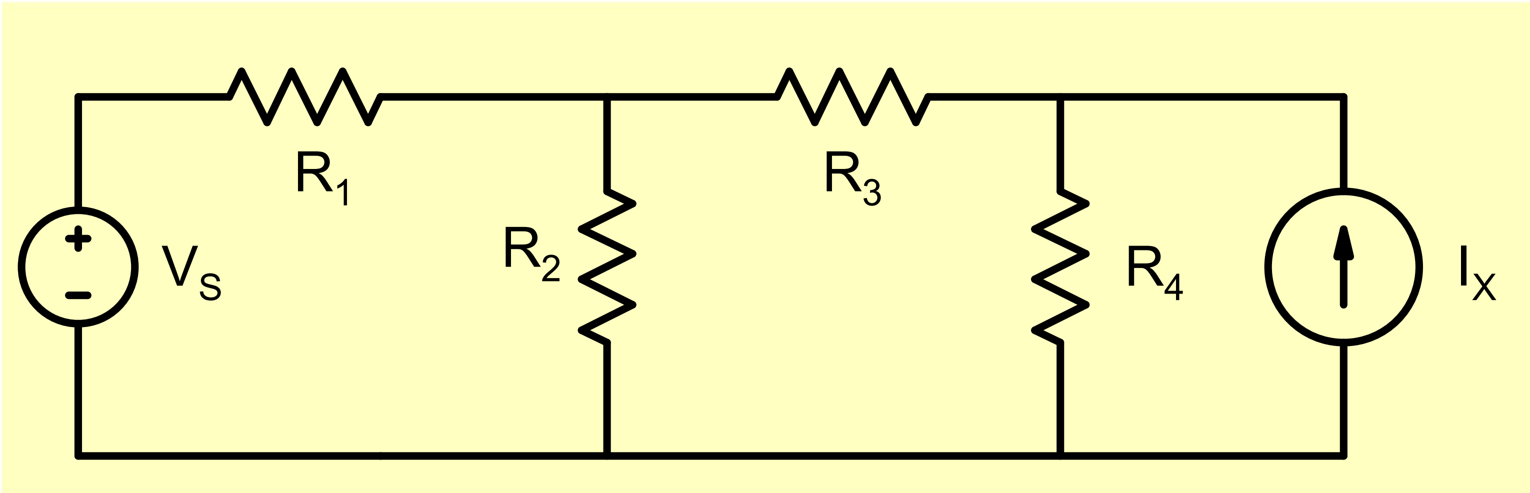


A ***loop is formed by tracing a closed path*** through circuit elements without passing through any intermediate node more than once



This is not a valid loop !

Circuit Analysis



What is current in R_2 ?

Procedure:

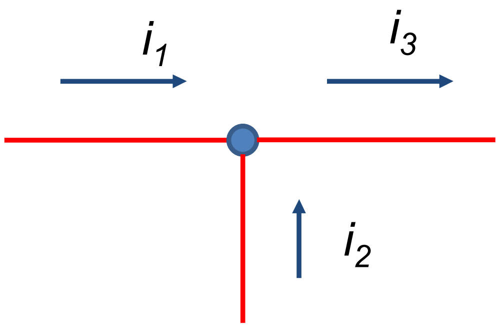
Use Kirchhoff's voltage law (KVL) and Kirchhoff's Current law (KCL) to transform the circuit into a set of equations whose solution gives the required voltage or current value

Kirchhoff's Current Law (KCL)

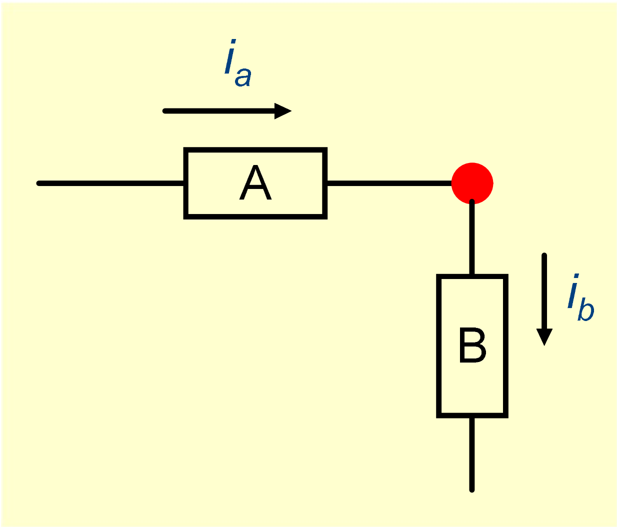
Net current entering a node is zero

$$\sum_{1}^{N} i_j = 0$$

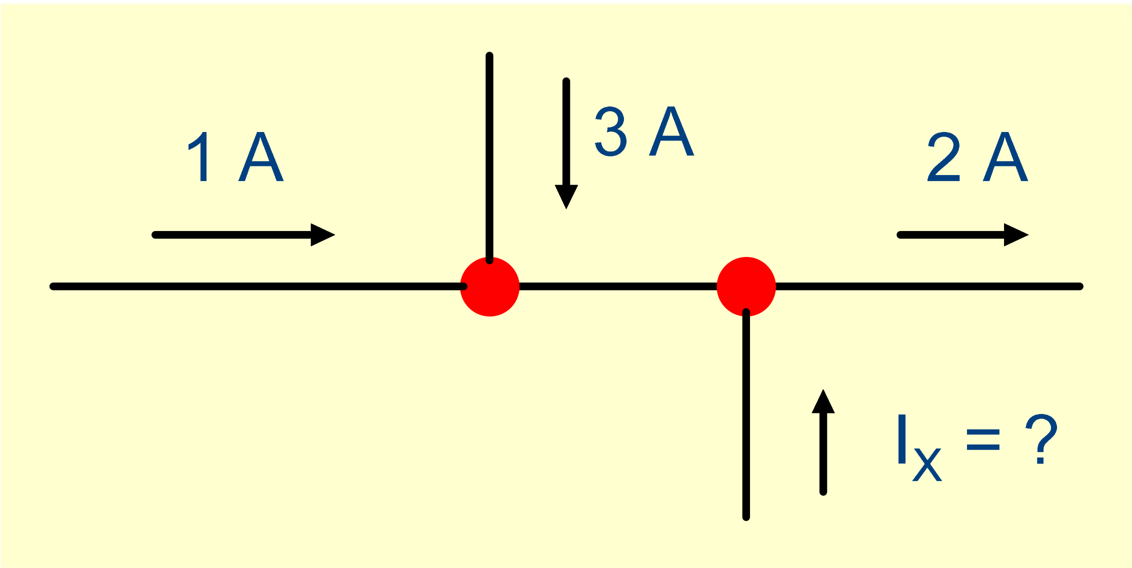
Current entering a node is considered positive and current leaving a node is considered as negative



$$i_1 + i_2 - i_3 = 0$$



$$i_a = i_b$$

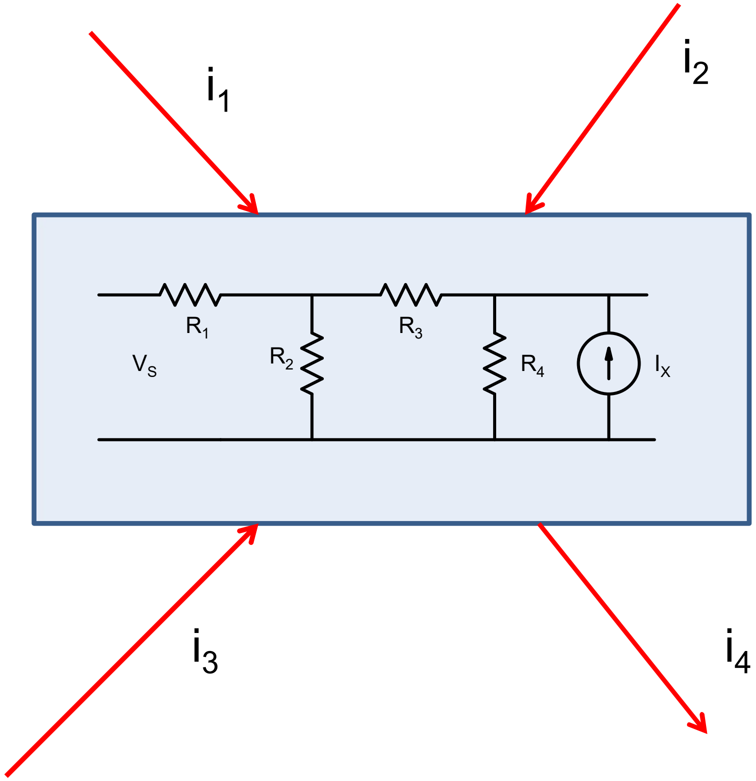


$$1 + 3 + I_x - 2 = 0$$

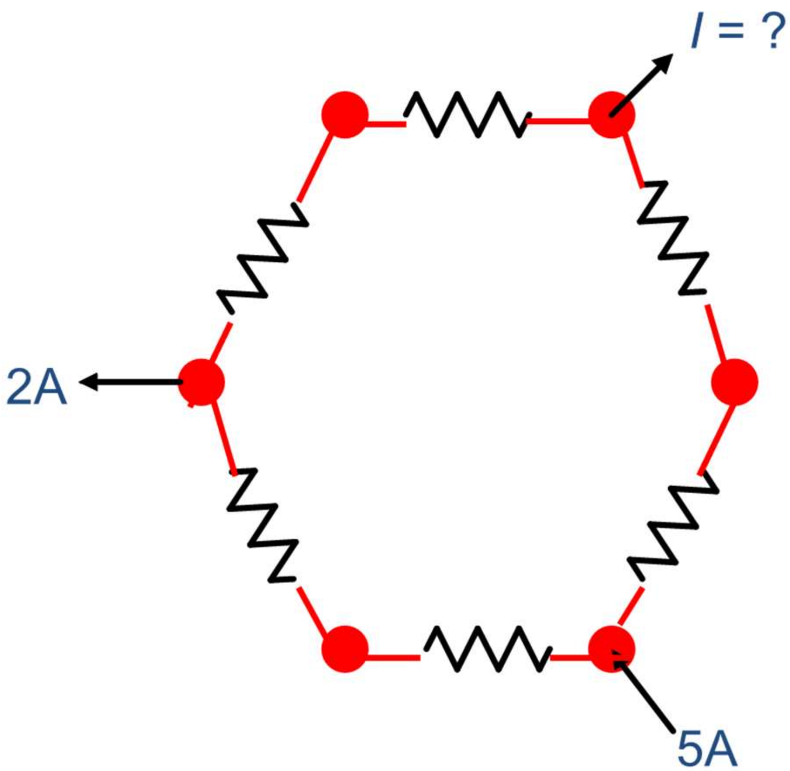
$$I_x = -2$$

KCL: More general formulation

The sum of currents entering/leaving a **closed surface is zero.**

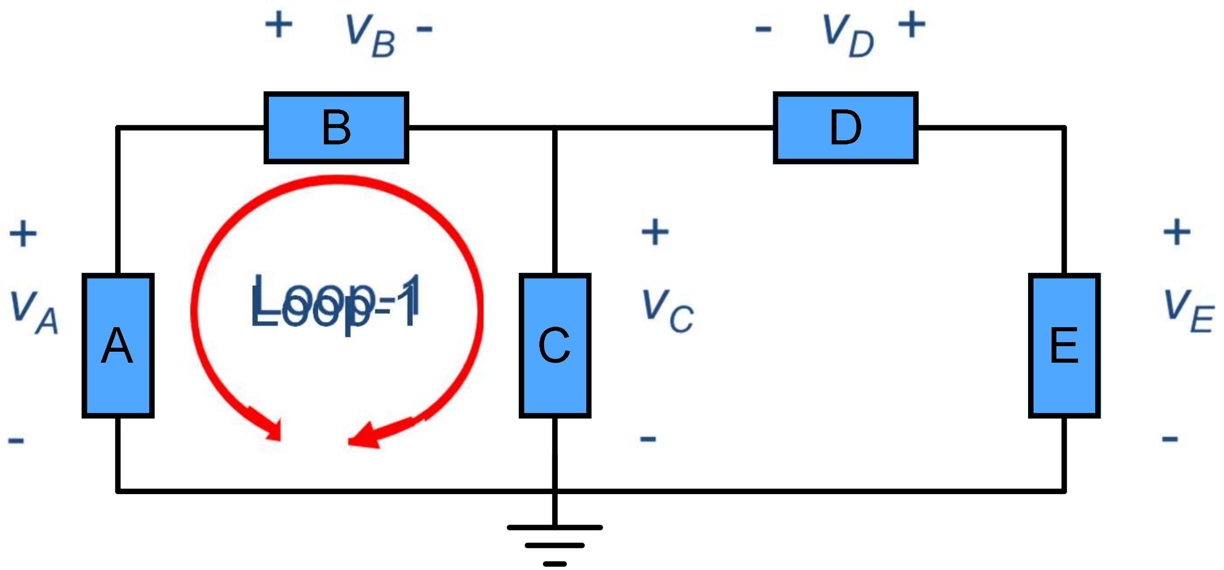


$$i_1 + i_2 + i_3 - i_4 = 0$$



Kirchhoff's Voltage Law (KVL)

The sum of the voltages for any closed path (loop) in an electrical circuit equals zero

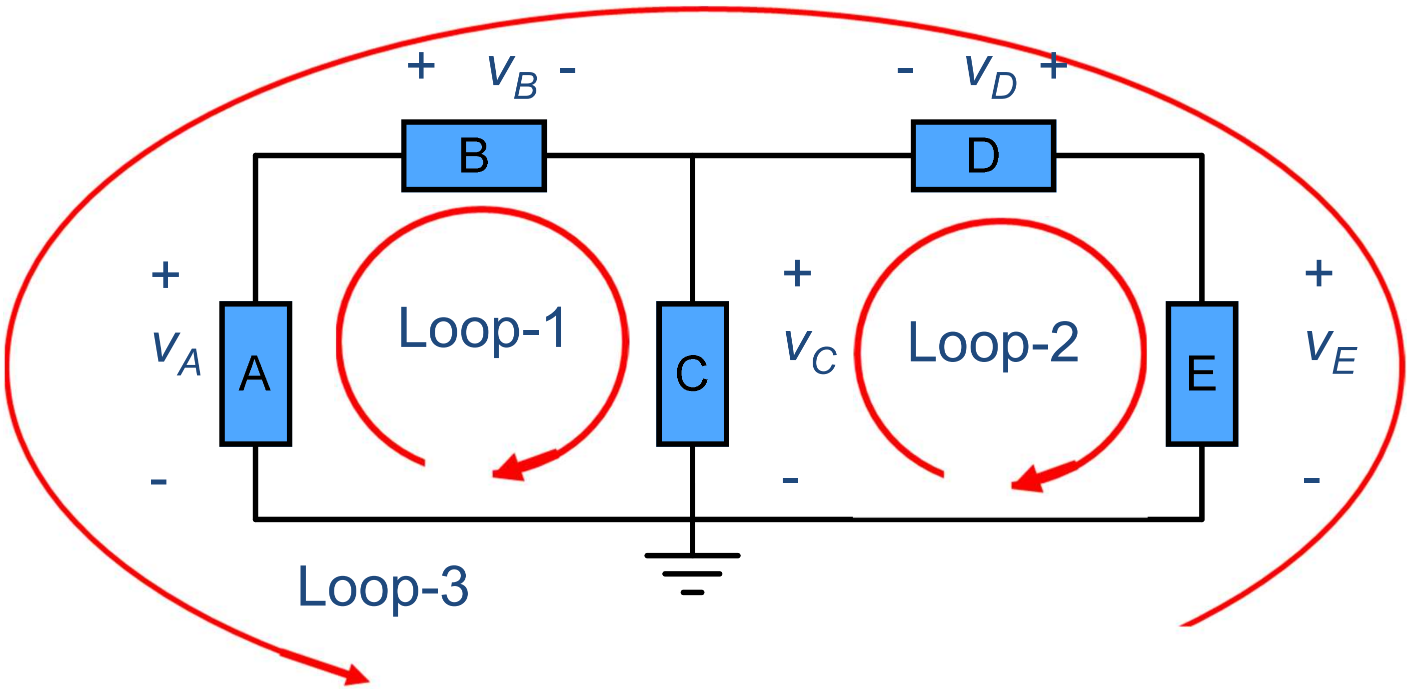


$$\text{Loop1}: -v_a + v_b + v_c = 0$$

$$\text{Loop1}: -v_c - v_b + v_a = 0$$

Voltages are added or subtracted depending on their reference polarities relative to direction of travel around the loop

Example

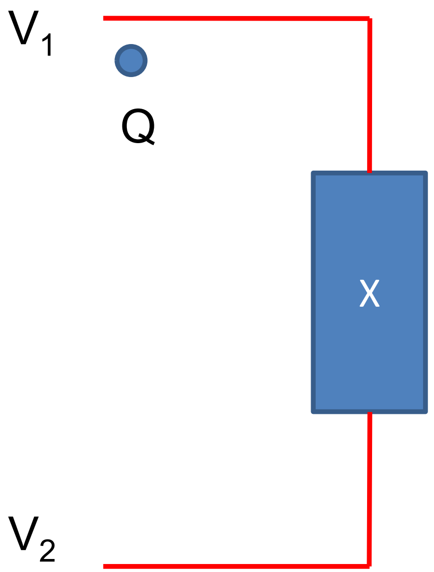


$$\text{Loop1}: -v_a + v_b + v_c = 0$$

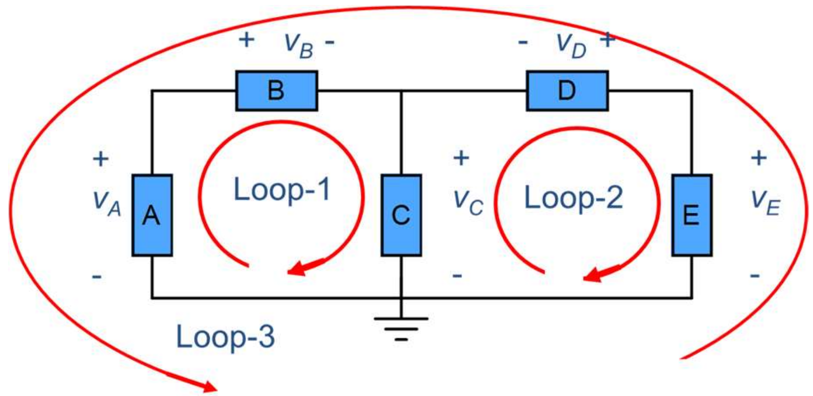
$$\text{Loop2}: -v_c - v_d + v_e = 0$$

$$\text{Loop3}: -v_e + v_d - v_b + v_a = 0$$

KVL and Conservation of Energy



The charge loses energy = Q x (V_1-V_2) Joules



$$\text{Loop1}: -v_a + v_b + v_c = 0$$

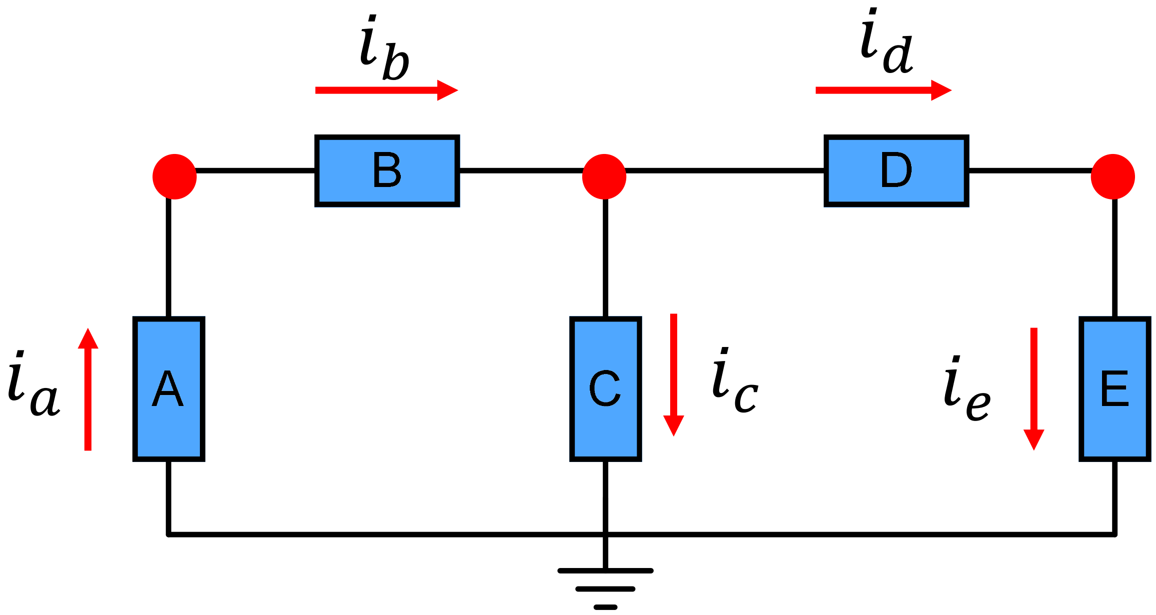
KVL: law of conservation of Energy

Energy gained

Energy lost

Series Connected Elements

Two elements are connected in series if there is no other element connected to the node joining them



A, B are in series

The elements have the same current going through them

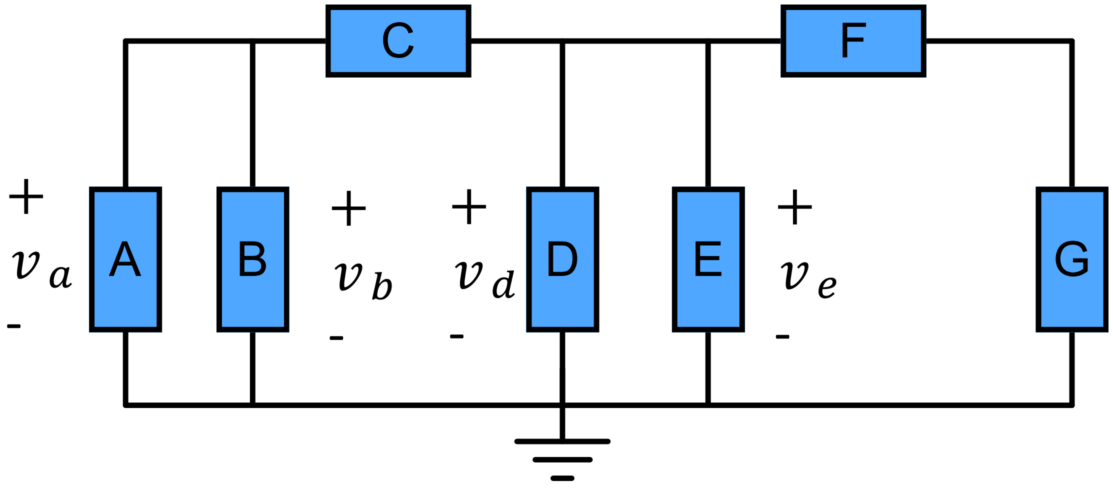
$$i_a = i_b$$

E and D are in series $\quad i_d = i_e$

B and C are not in series $\quad i_b \neq i_c$

Parallel Connected Circuit Elements

Two elements are connected in parallel if both ends of one element are connected directly to corresponding ends of the other



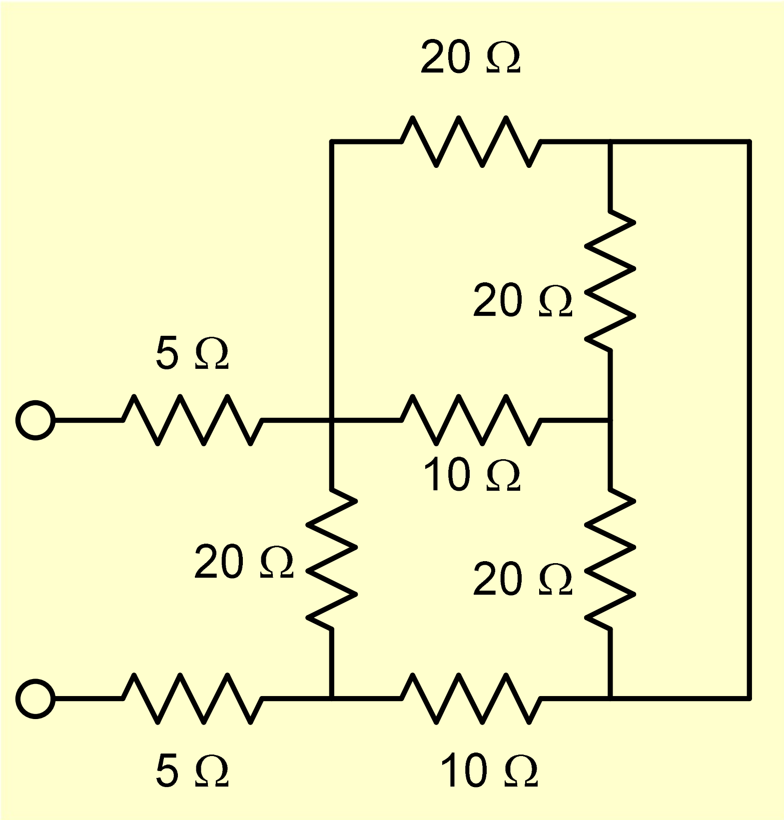
A and B are connected in parallel

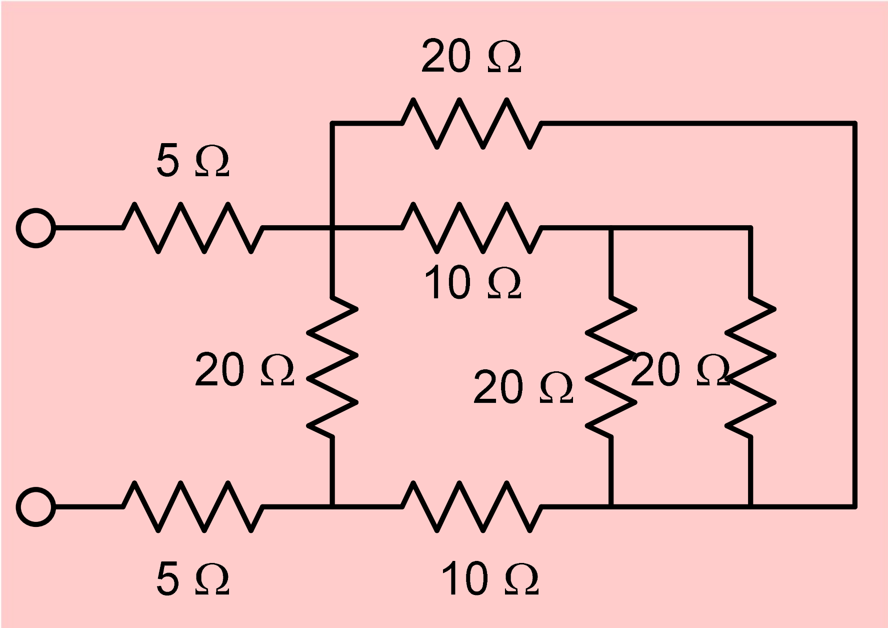
D, E are connected in parallel

$v_a = v_b$ $\quad$ $v_d = v_e$

The voltage across parallel elements are equal (both magnitude and polarity)

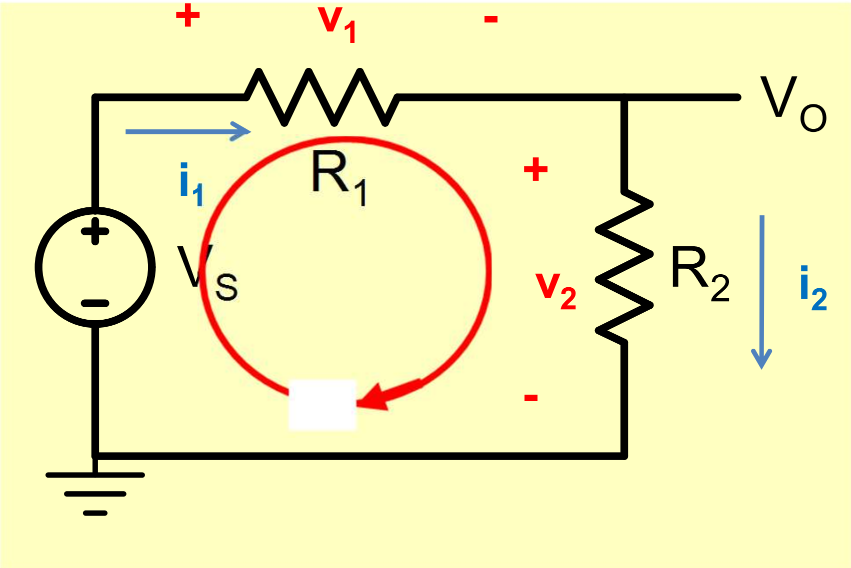
Identification of series or parallel connected elements may not be straightforward





Re-drawing of circuit often helps in visualization of simplification opportunities

Circuit Analysis



What is expression for current I_2 ?

Procedure:

Use Kirchhoff's voltage law (KVL) and Kirchhoff's Current law (KCL) to transform the circuit into a set of equations whose solution gives the required voltage or current value

$$KVL: \quad -V_S + v_1 + v_2 = 0 \Rightarrow V_S = v_1 + v_2$$

$$KCL: \quad i_1 - i_2 = 0 \Rightarrow i_1 = i_2 = i$$

$$Model\ of\ Resistor: \quad v_1 = i_1 \times R_1;\ v_2 = i_2 \times R_2$$

$$V_S = i \times (R_1 + R_2) \qquad V_O = i \times R_2$$

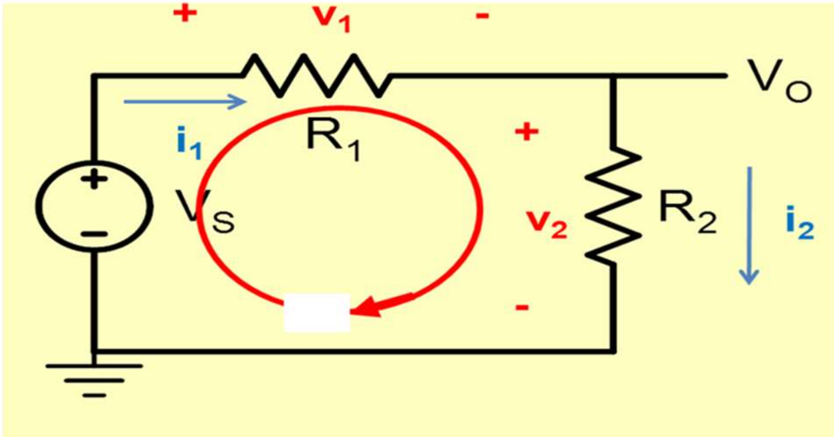
$$V_O = V_S \times \frac{R_2}{R_2 + R_1}$$

Circuit Analysis

Apply KVL and KCL

Use mathematical model of circuit elements

Solve the resulting system of Equations



$KVL: \quad -V_S + v_1 + v_2 = 0 \Rightarrow V_S = v_1 + v_2$

$KCL: \quad i_1 - i_2 = 0 \Rightarrow i_1 = i_2 = i$

$Model\ of\ Resistor: \quad v_1 = i_1 \times R_1;\ v_2 = i_2 \times R_2$

$V_S = i \times (R_1 + R_2) \qquad V_O = i \times R_2$

$$V_O = V_S \times \frac{R_2}{R_2 + R_1}$$

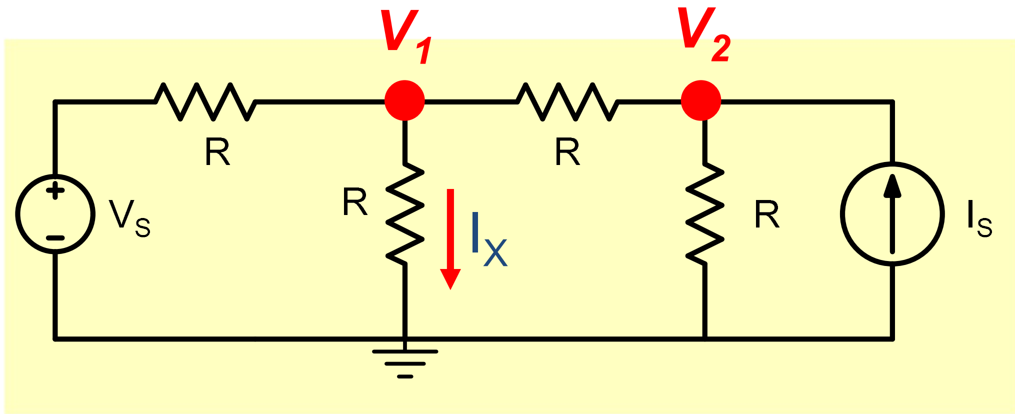
Circuit Analysis

Apply KVL and KCL

Use mathematical model of circuit elements

Solve the resulting system of Equations

Find I_X in the circuit shown:



$$\frac{V_S - V_1}{R} - \frac{V_1}{R} + \frac{V_2 - V_1}{R} = 0$$

$$\frac{V_1 - V_2}{R} - \frac{V_1}{R} + I_S = 0$$

Summary

Circuit Analysis

Apply KVL and KCL

Use mathematical model of circuit elements

↓

Solve the resulting system of Equations

Kirchhoff's Current Law (KCL)

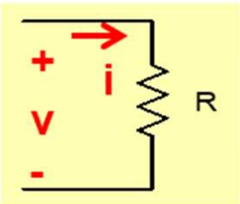
Sum of currents entering a node is equal to sum of currents leaving a node

Kirchhoff's Voltage Law (KVL)

The algebraic sum of the voltages equals zero for any closed path (loop) in an electrical circuit

Resistor

$$v(t) = R \times i(t)$$



$$P = i^2 \times R$$

$$P = \frac{v^2}{R}$$

Two elements are connected in series if there is no other element connected to the node joining them. Same current flows

Two elements are connected in parallel if both ends of one element are connected directly to corresponding ends of the other. **Same voltage**